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Functional and Operating Requirements for the Microreactor Agile Non-Nuclear Experimental Test Bed (MAGNET)

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1. INTRODUCTION

Microreactors, or small, transportable reactors with a capacity of < 20 MW_{TH}, are sought to provide heat and power for myriad applications in remote areas, military installations, emergency operations, humanitarian missions and disaster relief zones as illustrated in Figure 1. These small, transportable reactor designs, while offering many advantages, are largely untested and unproven. System and component testing is needed to demonstrate to regulators that these designs are safe and to convince customers that the systems are robust, reliable, and efficient.

Figure 1: Applications for Microreactors

The microreactor agile non-nuclear experimental test bed (MAGNET) is being constructed at Idaho National Laboratory to assist with the development, demonstration, and validation of microreactor components and systems. MAGNET will support technology maturation to reduce uncertainty and risk relative to the operation and deployment of this unique class of systems. Stakeholders for this test bed include microreactor developers, energy users, and regulators. Regulators will be engaged early in the design and testing to expedite regulatory approval and licensing.

Within MAGNET, systems and components can be safely tested, providing valuable information on operating regimes, failure modes, and thresholds. Since there are various types of microreactors being proposed, which can be classified according to their core cooling method, heat-pipes, gas-cooled (pebble bed or prismatic), molten salt, light water, or light water, the goal is to provide a test bed that is broadly applicable to multiple microreactor concepts. Each reactor type poses a different set of design and operational challenges and performance claims stated by commercial vendors have not been independently verified through rigorous testing. The initial set of tests to be performed in MAGNET are targeted towards demonstrating the feasibility and performance of heat-pipe cooled reactors, since this concept is unique to very small nuclear reactors. However, the testbed will be constructed to accommodate other designs in addition to heat-pipe cooled reactors

To increase the technological maturity of microreactors, MAGNET is being designed to:

- Provide displacement and temperature field data that can be used to verify potential design performance and validate accompanying analytical models
- Assess structural integrity of the core block, i.e., thermal stress, strain, aging/fatigue, creep, deformation
- Evaluate interface between simulated reactor components and heat exchanger for both geometric compatibility, functionality, and heat transfer capabilities
- Test the interface of the heat exchanger to auxiliary systems, such as power conversion systems for energy production, process heat applications or production of chemicals, clean water, or other commodities
- Demonstrate the applicability of advanced manufacturing (AM) techniques, such as additive manufacturing and high-temperature bonding techniques, for nuclear reactor applications
- Deploy advanced sensors for in operando data collection and monitoring
- Study the effects of cyclic loading on materials and components
- Enhance readiness of new or novel reactor components, such as heat pipe technology

Performance testing of systems or relevant components will be conducted under prototypical conditions that ensure safe operation of the microreactor. This performance testing will focus on thermal and structural performance. MAGNET will have the capability to connect to potential auxiliary systems, e.g., power conversion unit (PCU), desalination equipment, chemical processes, district heating. MAGNET will not simulate all physical processes and phenomena, only some that yield important safety and performance.

MAGNET will be configured in a plug-and-play arrangement. Modeling and simulation (M&S) will be employed to aid in the design of experiments. Such information will be extremely helpful in guiding the placement of sensors and predicting operating performance under a range of normal or accident conditions. M&S will also prove useful in the scaling of prototypical hardware for each test. The use of computational control and model feedback will emulate thermal response times and magnitudes.

2. FACILITY INTERFACES

Requirements for the various systems and interfaces are outlined below. The testing may be performed either at the component or system level.

2.1 Piping/Ducting

The capability for exhaust or recirculation of test article coolant fluids will be provided.

2.2 Environmental Enclosure

The test article will be enclosed within an environmental chamber (EC) to facilitate the testing under vacuum or inert gas conditions. The EC will provide a non-water-based fire suppressant. The EC will also serve to provide containment in the event of heat pipe failure and release of sodium

2.3 Indoor Testing

The entire unit will be configured to accommodate testing indoors in the ESL high bay with the test bed mounted on a skid.

2.4 Noise Abatement

Equipment such as compressors, blowers, and turbines, that generate ambient noise, will be set on concrete pads outside the building.

2.5 Floor Loading

The maximum floor loading at the test bed location within ESL D100 is 1000 lb/ft^2 which applies to the total load of all of the equipment placed on the concrete floor or pad. The load of the test bed will be distributed by means of the skid on which it resides.

2.6 Floor Penetrations

No penetrations are allowed in the floor due to installed hydronic floor heating system.

2.7 Electrical Power

Current service available at ESL D100 includes 2400 A at 480 V and 600 A at 208 V.

2.8 Pressure

The test bed must be able to test components in a vacuum or at atmospheric pressure in air, N_2, or an inert gas.

2.9 Gas Supply

Tests may require a supply of an inert gas, such as N_2, He, or Ar. Initial testing is planned with N_2 serving as the coolant in the heat removal section and with the test chamber at a vacuum or backfilled with an inert gas

2.10 Microgrid Connection

The INL microgrid test bed will be available to connect to MAGNET.

2.11 Tenant Use Restrictions

The ESL is in a leased building that has tenant use restrictions. For example, nothing can be bolted to the floor, and there is no gantry crane.

3. SYSTEM DESCRIPTION

The first set of tests will be conducted using a non-nuclear test article that incorporates heat pipes for core heat removal. Electric heaters will simulate the heat generated by the nuclear fuel. A compressed, inert gas flowing through an enclosed loop will remove heat from the test article. Except for the test article, supporting systems within MAGNET will meet all applicable codes and standards.

3.1 Initial Test Article Specifications

- Heat-pipe cooled
- Power: nominal 75 kWth (37 heat pipes at ~2 kW/heat pipe); maximum power up to 100 kW
- Heat pipe working fluid: Na
- Surface temperature at evaporator section of the heat pipe: 650 °C (this temperature is not for the gas cooling system and only applies to the surface temperature of the heat pipe)
- Coolant for heat removal section: compressed N_2 or He gas ≤ 20 bar_g
- Core block and heat removal section material: stainless steel 316L
- Heat removal and core block section lengths: < 1 m each (< 2 m overall length)
- Heat pipe and wick material: 316L
- Simply supported test article
- Interfaces to future power conversion unit (PCU), PCU simulator, or other auxiliary system
- Checked and approved drawings with appropriate dimensioning and tolerancing shall be generated for all test article and test bed components (test article design will be completed by the research teams at INL and LANL)
- All material certifications shall be kept on a common file space
- Test article will be fabricated using best available engineering practices

3.2 Test Article Thermal Requirements

- Test article temperatures will range from room temperature up to 750 °C, and heat shields and/or insulation will be placed on the test article to minimize heat loss and to protect sensitive equipment and the test bed enclosure (this temperature applies to the test article only and not the gas cooling system)
- Resistive heaters will provide a non-nuclear heat source to emulate reactor thermal power and decay heat
- Test article heater power ≤ 250 kW
- Nominal test article core and heat pipe operating temperature is 650 °C (this temperature applies to the heat pipe and test article only)
- For the closed-loop configuration, the chiller that has been configured for the thermal energy delivery system (TEDS) will provide an ultimate heat sink
- A recuperative heat exchanger shall be incorporated to recover as much heat as possible from the test article

3.3 Electrical Requirements

- Electrical service up to 250 kW (208 V / 1 phase) is required for the test article heater section; the initial test article heater section will require 75 kW
- MAGNET skid to include 480 V – 208 V transformer

- Electrical service requirements for large electrical loads shown in Table 1
- Additional 120 V / 1 phase ancillary power for support systems including instrumentation, data acquisition, etc.
- Electrical safety reviews will be implemented
- Electrical grounding implications will be reviewed before instrumentation integration
- Appropriate electrical schematics will be generated and documented for the systems

Table 1 Major Component Electrical Requirements

Component	Voltage (V)	Phase	Power
Enclosure Chamber (Vacuum pump)	480	3	4.5 kW
Recirculating Blower	480	3	35 HP
Cartridge Heaters (54 required – see Figure 4)	208	1	75 kW

3.4 Environmental Chamber Requirements

- Chamber capable of an inert environment, down to 15 ppm O_2, by successive dilution or other methods
- Chamber rated to 10^{-4} torr vacuum
- Chamber sized to accommodate instrumentation and test article contingencies (Figure 3)
- Chamber to meet applicable codes and standards
- Test bed construction complies with industry standard safety practices
- Pressure safety reviews shall be implemented

3.5 Testing Requirements

- Experiments shall be capable of up to 300 hours of continuous testing with unattended operation
- Test article shall be horizontally oriented
- Test matrix shall be designed to observe transient system response during heat up and cool down, startup of heat pipes, effects of non-uniform heating, and effects of heat pipe failure
- Test articles to be operated in horizontal orientation
- A point kinetic, zoned, heater control model will be developed to simulate nuclear fuel reactivity feedback

3.6 Flow Loop Temperature and Pressure Requirements

- The flow loop shall be constructed for a design pressure of 22 bar_g
- The flow loop shall be constructed for the design temperatures indicated in the P&ID (Figure 2) - the highest design temperature in the flow loop is 650 °C at the outlet of the environmental chamber
- Flow Loop Process Control, Instrumentation, and Data Acquisition Requirements
- Mass flow meter for gas coolant

- Core heater power (either individual heaters or groups)
- Chilled water flow rate and inlet and outlet temperatures
- Various temperatures on the surface and internal to the test article
- Advanced instrumentation as determined by the research team
- Sufficient feed-throughs on environmental chamber for unforeseen instrumentation
- Data acquisition to record all flow loop process parameters
- Expandable data acquisition to record test article parameters as defined by experiment stakeholders

3.7 Project Requirements

- The graded approach for quality applies
- Incremental testing shall be conducted to control risk
- Project files shall be shared via secure file server
- All key findings shall be documented and checked for technical accuracy
- All procured components shall be traceable and documented on common file server
- Appropriate P&IDs shall be generated for the system
- Where applicable, vetted vendors will be selected with NQA-1 compatible quality programs (for future commercial grade dedication)

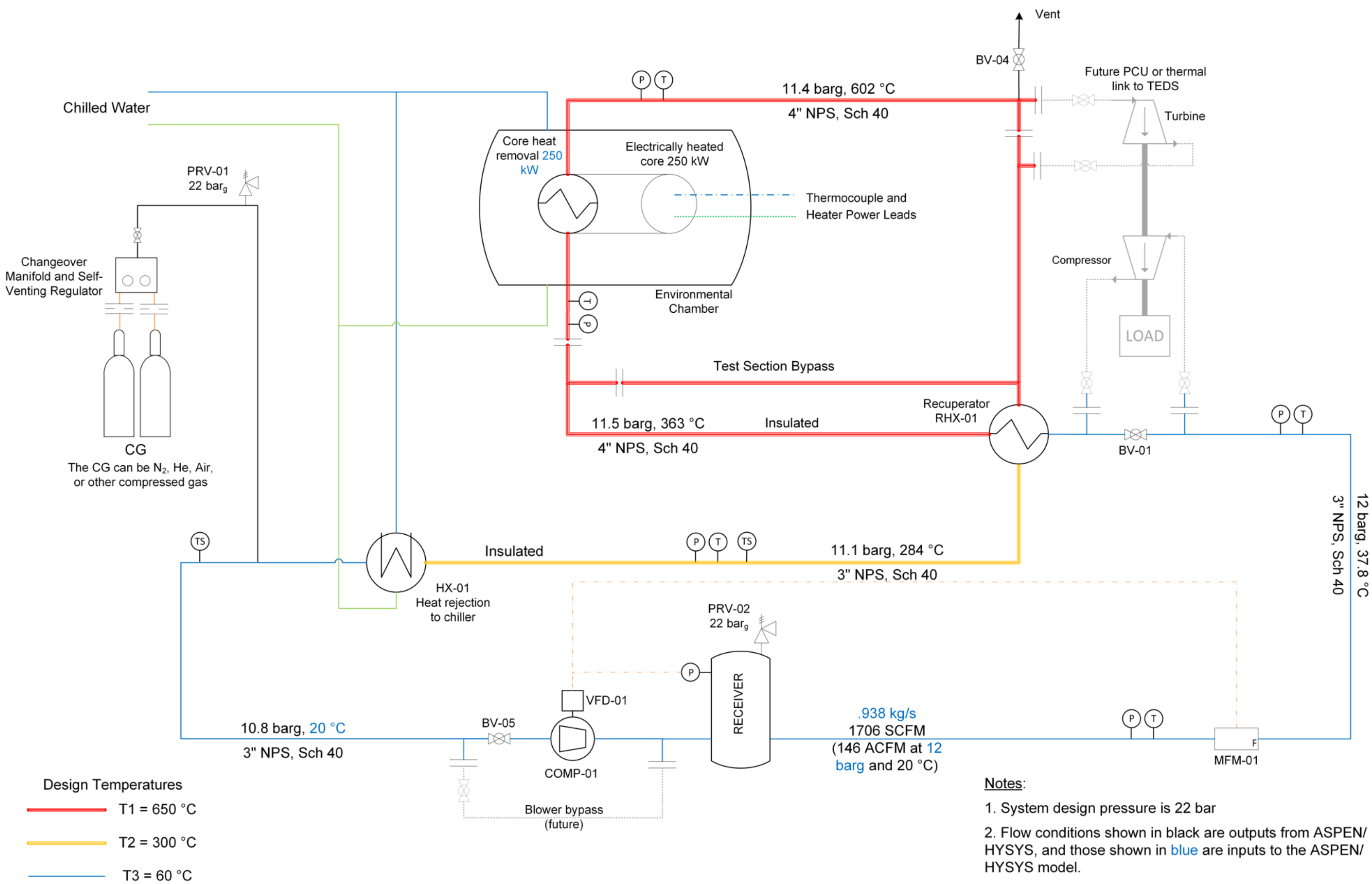
Vent
BV-04
Future PCU or thermal link to TEDS
Turbine
Compressor
LOAD
11.4 barg, 602 °C
4" NPS, Sch 40
Chilled Water
Core heat removal 250 kW
Electrically heated core 250 kW
Thermocouple and Heater Power Leads
Environmental Chamber
PRV-01
22 barg
Changeover Manifold and Self-Venting Regulator
CG
The CG can be N_2, He, Air, or other compressed gas
Test Section Bypass
11.5 barg, 363 °C
Insulated
4" NPS, Sch 40
Recuperator RHX-01
BV-01
12 barg, 37.8 °C
3" NPS, Sch 40
Insulated
11.1 barg, 284 °C
3" NPS, Sch 40
HX-01
Heat rejection to chiller
PRV-02
22 barg
RECEIVER
VFD-01
BV-05
COMP-01
Blower bypass (future)
10.8 barg, 20 °C
3" NPS, Sch 40
.938 kg/s
1706 SCFM
(146 ACFM at 12 barg and 20 °C)
MFM-01
Design Temperatures
T1 = 650 °C
T2 = 300 °C
T3 = 60 °C
Notes:
1. System design pressure is 22 bar
2. Flow conditions shown in black are outputs from ASPEN/HYSYS, and those shown in blue are inputs to the ASPEN/HYSYS model.

Figure 2: Test Bed P&ID

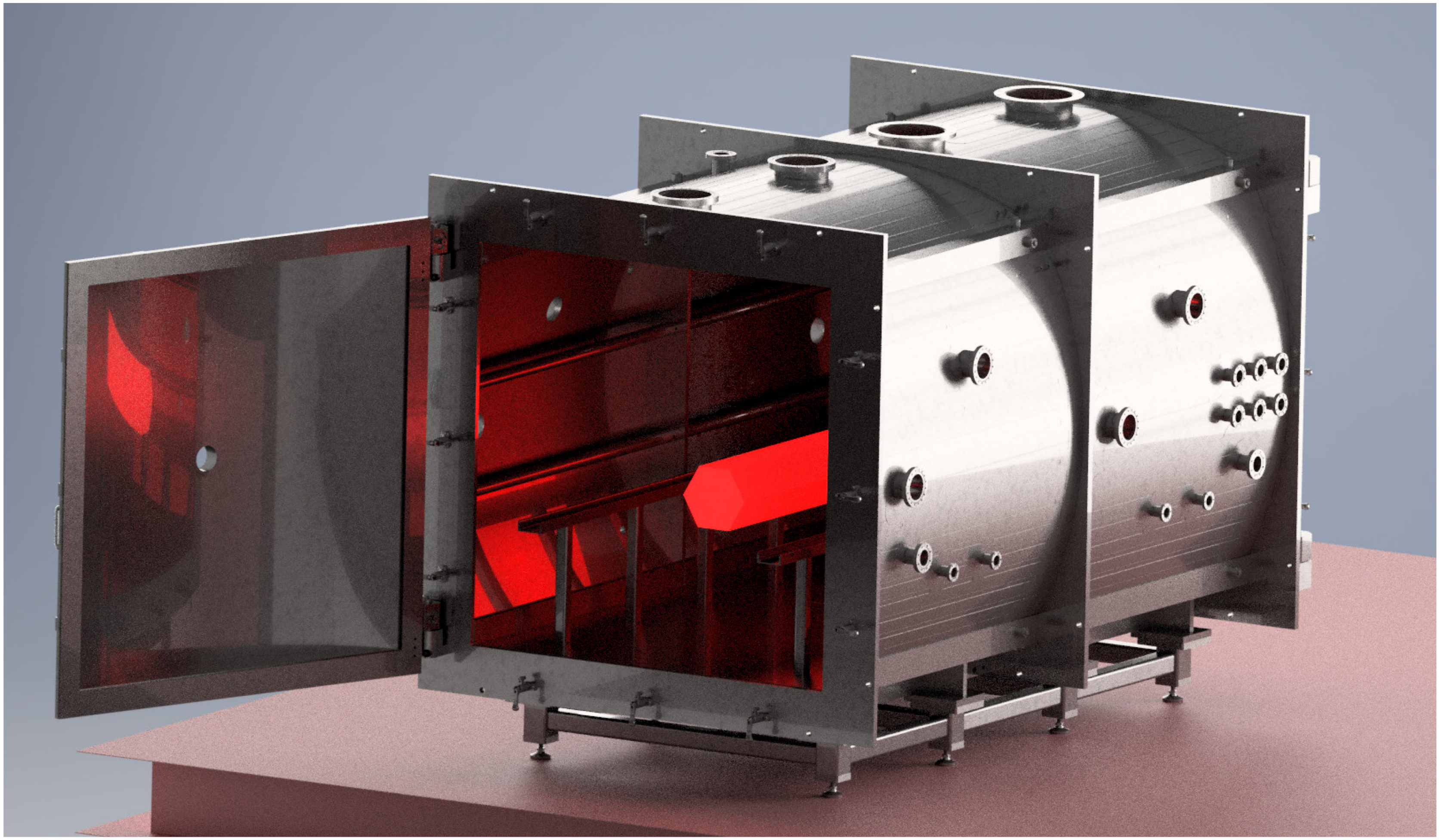

Figure 3: Rendering of Test Bed Skid and Vacuum/Inert Chamber Showing Door and Test Article Inside

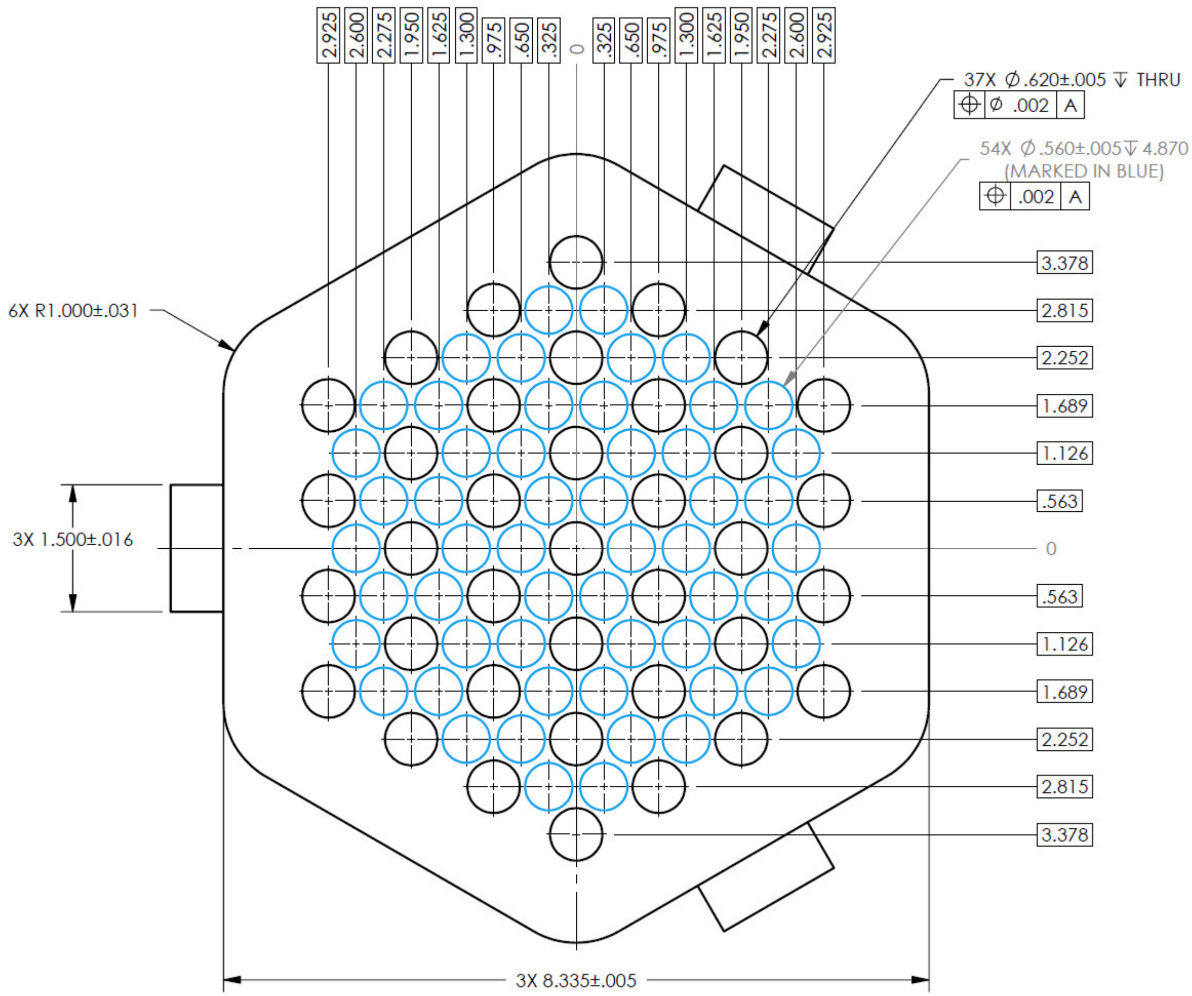
2.925
2.600
2.275
1.950
1.625
1.300
.975
.650
.325
0
.325
.650
.975
1.300
1.625
1.950
2.275
2.600
2.925
37X ∅.620±.005 ⊽ THRU
⌖ ∅ .002 A
54X ∅.560±.005⊽ 4.870
(MARKED IN BLUE)
⌖ .002 A
6X R1.000±.031
3.378
2.815
2.252
1.689
1.126
.563
0
.563
1.126
1.689
2.252
2.815
3.378
3X 1.500±.016
3X 8.335±.005

Figure 4: Cross Section of Core Geometry, 37 Heat Pipe, 75 kW Test Article (black circles indicate heat pipe locations, blue circles indicate heater locations)